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The LSND Experiment and the Zee Model

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A recent experiment LSND at Los Alamos has provided[1] an indication of $\overline{\nu}_\mu - \overline{\nu}_e$ oscillations with Δm^2 of order 1ev^2 or greater and $\sin^2 2\theta_{e\mu}$ between 2×10^{-3} and 10^2. Such a value of Δm^2 for $\nu_\mu - \nu_e$ oscillations was not expected in the standard see-saw model[2] suggested by SO(10) with a large mass hierarchy because it leads to too large a value of $m(\nu_\tau)$ to fit cosmological constraints. Furthermore within that model the LSND result is inconsistent with the indications of oscillations from both atmospheric neutrinos[3] and solar neutrinos.[4]

Here we reconsider an alternative model proposed by Zee.[5] This represents the most direct way to produce Majorana neutrino masses in a theory such as SU(5) in which right-handed neutrinos are totally absent. The general features of masses and mixings in this model have been analyzed.[6] The mass matrix has the form

$$m_0^2 \begin{pmatrix} 0 & \sigma & \cos\alpha \\ \sigma & 0 & \sin\alpha \\ \cos\alpha & \sin\alpha & 0 \end{pmatrix}$$

where σ is of order $(m_\mu^2/m_\tau^2) \approx 10^{-2}$ to 10^{-3}. The eigenstates to a good approximation are

$$\begin{aligned} N_1 &= \nu_e \sin\alpha - \nu_\mu \cos\alpha \\ \sqrt{2} N_2 &= \nu_\tau + \nu' \\ \sqrt{2} N_3 &= \nu_\tau - \nu' \\ \nu' &= \nu_e \cos\alpha + \nu_\mu \sin\alpha \end{aligned}$$

The state N_1 has a small mass of order σm_0^2 whereas N_2 and N_3 have masses of order m_0^2 with a mass splitting

$$\Delta m_{23}^2 = 2 m_0^2 \sigma \sin 2\alpha. \tag{1}$$

The following features follow from these equations:

1. There exist two very different values for Δm^2. The large value $\Delta_L \approx m_0^2$, corresponding to short wave-length oscillations applies only to $\nu_\mu - \nu_e$ oscillations.

2. There are oscillations of ν_μ to ν_τ and ν_e to ν_τ corresponding to a much smaller value of Δm^2, Δ_s, given by Eq. (1).

3. If the mixing angle for the short-wave length $\nu_\mu - \nu_e$ oscillations is α, then the amplitudes of the oscillations involving Δ_s are given by $\cos^2\alpha$ and $\sin^2\alpha$, one corresponding to $\nu_\mu - \nu_\tau$ and the other to $\nu_e - \nu_\tau$.

4. There exist two massive neutrinos almost degenerate in mass with masses given by $\sqrt{\Delta_L}$.

To apply this theory to the LSND experiment we take as an example $\Delta_L = 6\text{ev}^2$. The theory then gives two massive neutrinos with masses each about 2.5 ev; such a scenario has been suggested as being very useful for cosmology.[7] Indeed the interpretation of the LSND experiment in terms of two almost degenerate massive neutrinos has been suggested in various papers[8]; it is required in the Zee model.

From the LSND value of α it follows that either ν_e or ν_μ has almost complete mixing with ν_τ while the other has an amplitude of oscillation of order 10^{-3}. For our example from Eq. (1), Δ_s is of order of magnitude 10^{-2} to 10^{-3} ev^2. Thus one of the two possibilities corresponds to complete $\nu_\mu - \nu_\tau$ mixing with a value of Δ_s appropriate to explain the atmospheric neutrino results. There is in this case no explanation of the solar neutrino results. The other possibility provides no explanation of the atmospheric neutrino results and indeed Δ_s should be down to 10^{-3} ev^2 so as not to exacerate this problem; it does provide a prediction that the solar neutrino ν_e flux is reduced by a factor of 2.

While this does not provide a perfect explanation of the solar neutrino results, it does explain the gallium and Kamiokande results within their 1σ experimental errors. However, even taking into account the uncertainty in the ^8B flux there is at least a 3σ discrepancy with the Davis result.

In conclusion the LSND result combined with the Zee model leads to the interesting *predictions* there are two neutrinos almost degenerate with masses of interest for cosmology and that a large neutrino oscillation signal should be seen in either the atmospheric neutrinos or the solar neutrinos.

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References

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